ERDC/TN RSM-20-4
April 2020

Seamless Integration of Lidar-Derived Volumes and Geomorphic Features into the Sediment Budget Analysis System

by Lauren Dunkin, Eve Eisemann, Michael Hartman, Jennifer Wozencraft

PURPOSE. This Regional Sediment Management Technical Note (RSM-TN) provides a workflow and case study documenting the process to integrate lidar-derived volume changes and changes quantified from geomorphic features into the Sediment Budget Analysis System (SBAS). Sediment budgets provide an understanding of a region's sediment sources, project needs, processes, data gaps, engineering actions, and ecological considerations. Elevation data from profiles or lidar, sediment characteristics, dredging and placement information, along with other coastal datasets, are used to understand sediment pathways and develop sediment budgets for a region. Workflows and tools have been updated or modified to integrate sediment budget tools (SBAS), volume change tools (Joint Airborne Lidar Bathymetry Technical Center of Expertise [JALBTCX] Volume Change Toolbox), and remote sensing data for the creation of comprehensive regional sediment budgets.

BACKGROUND: Sediment budgets provide valuable information about sediment pathways in the coastal zone and are the first step in the Regional Sediment Management (RSM) process to gain a better understanding of the region (Rosati 2005). Sediment budgets are an accounting of sediment inputs (sources), outputs (sinks), and change in sediment volume for a defined area within a specified time period. The three types of sediment budgets range in complexity and include the (1) conceptual budget to provide reconnaissance level information, (2) interim to provide a working budget for initial analyses, and (3) operational budget, which is the final budget. A conceptual sediment budget provides a scoping level effort that is valuable for data gathering and understanding the region (Dolan et al. 1987; Kana and Stevens 1992). The interim budget is the transitional model between the scoping level phase and the operational budget. An operational budget is used in regional planning and initial design of site-specific projects.

The US Army Engineer Research and Development Center has developed tools and technologies like SBAS to support the creation of sediment budgets. In addition, spatial datasets, such as those collected as part of the National Coastal Mapping Program (NCMP), are available to provide regional, high-resolution elevation data that may be used to derive inputs for sediment budgets. Further, the JALBTCX Volume Change Toolbox provides a straight-forward process to quantify coastal change and also supports the creation of bins that may be used to define littoral cells (Robertson et al. 2018). This RSM-TN outlines the data and tools needed to develop sediment budgets cells and incorporate coastal change results.

Quantifying Coastal Change. Multi-year, regional topographic/bathymetric lidar datasets collected through the NCMP are available for all the coastal regions of the contiguous United States, including the Great Lakes. These datasets cover the most active sediment transport zone, making them ideal to support sediment budget efforts. The expansive geographic region included in sediment budgets benefit from the integration of remote sensing data collected regionally on a recurring basis. NCMP frequently surveys impacted sections of coastline following severe storms, making post-storm data available for crucial storm sediment transport assessments.

The repeat lidar digital elevation models (DEMs) produced by the NCMP are used to derive a number of valuable coastal change parameters including qualitative erosion/deposition maps, quantified volume changes, shoreline change, as well as bluff and dune feature changes (where present).

A shoreline can be delineated by contouring the coastal DEM at the mean high water (MHW) level or another consistent chosen elevation. Average shoreline change rate in the cross-shore direction is calculated as the distance the shoreline has migrated over the time between surveys. Shoreline change analyses provides a valuable two-dimensional look at the impact of storm and fair-weather periods, as well as coastal or inland structures and engineering projects, particularly when there are numerous shoreline datasets for a given area (Camfield and Morang 1997). Other coastal features, including dunes and bluffs, are delineated using these DEMs. Bluffs are particularly important for sediment budget applications in the Great Lakes region because erosion of bluffs provides both the primary source of sediment to the nearshore zone as well as a hazard to land owners and infrastructure as bluff retreat encroaches on properties (Baird & Associates 2002; Cross et al. 2016). The process of delineating these features is more complex than creating a shoreline as they are not ubiquitous along a shoreline and do not always exist at the same elevation.

Multiple DEMs produced for the same coastal region from repeat lidar collections can be used to create difference grids, which illustrate patterns of erosion and deposition along a coastline. Sediment volume changes are quantified by summing difference grid values within a specified area. A negative volume change indicates that sediment was removed from the area by erosion or removal, and a positive change will indicate deposition or placement.

JALBTCX VOLUME CHANGE TOOLBOX: The JALBTCX Volume Change Toolbox (Version 1, 2016) is an ArcPy toolset that produces coastal volume change and shoreline change metrics from two spatially overlapping DEMs. The DEMs can be generated from topographic and bathymetric lidar datasets, transects, or contours from historic charts, maps, or aerial imagery. Data gaps should be minimized and accounted for in the uncertainty bounds within the SBAS. The basic steps of the process include generating an approximately shore-parallel baseline to delineate the landward extent of the analysis, the generation of baseline-perpendicular transects at a given spacing, and the generation of analysis masks or predefined regions of interest within the bins between transects (Figure 1). The JALBTCX Volume Change Toolbox uses the ArcGIS Zonal Statistics tool, which is in the suite of Spatial Analyst tools to calculate volumes for each bin. The volumes are calculated within the entire bin as well as areas above and below the MHW line using the MHW mask to determine subaerial and subaqueous sediment volume changes, respectively (Figure 2).

Specific metrics produced using the JALBTCX Volume Change Toolbox include shoreline change, total volume change, as well as above and below MHW volume change. The final output is a geodatabase containing the DEMs, difference grids, and an analysis sections shapefile. This shapefile contains the analysis mask and bins. Each bin has attributes for each metric, including the total, above and below MHW volume change in cubic yards or cubic meters, as well as volume density change in cubic yards per year per linear foot or cubic meters per year per meter. The volume density is the time-averaged volume change within each bin per unit length of shoreline covered by that bin. An example of results for the Lake Michigan area is shown in Figure 3. The volume change results are available for each bin along the shoreline with the erosional bins shown as red to yellow and the accretional bins shaded with the tan to green. Figure 3 inset is a zoomed-in view of the elevation difference grid for the region around St. Joseph inlet. Areas of erosion are shaded with purple while areas of accretion are shaded green. Regions with little change are identified by the yellow color.

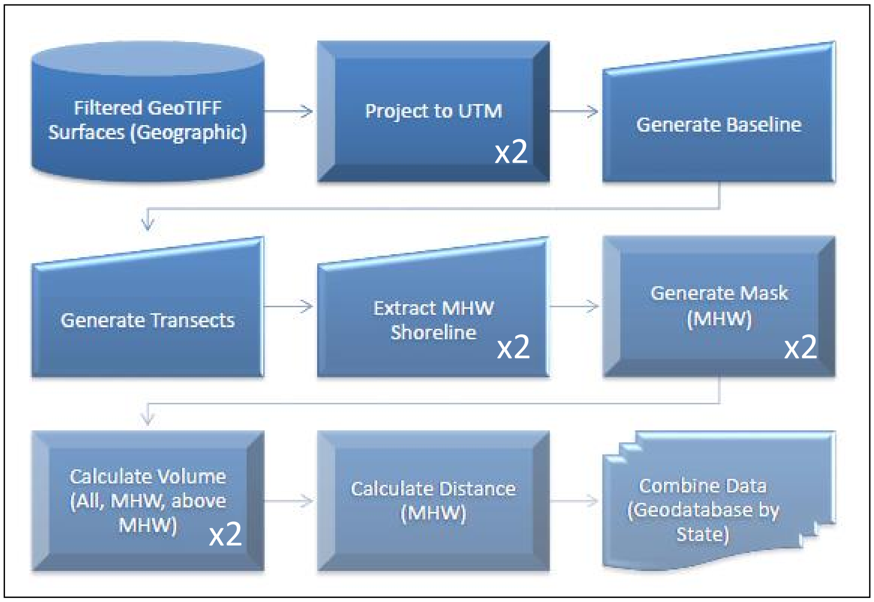

Figure 1. JALBTCX Volume Change Toolbox generalized process where the X2 indicates that each dataset must be processed for the two datasets used in the volume calculation (adapted from Robertson et al. 2018).

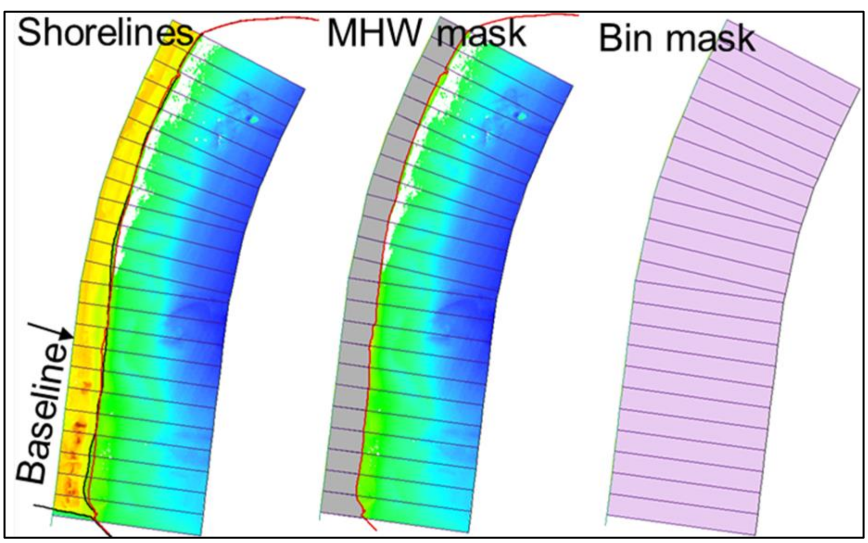

Figure 2. Steps in the JALBTCX Volume Change Toolbox include the generation of a baseline, extraction of shorelines from both DEMs, and the creation of MHW and Bin analysis masks.

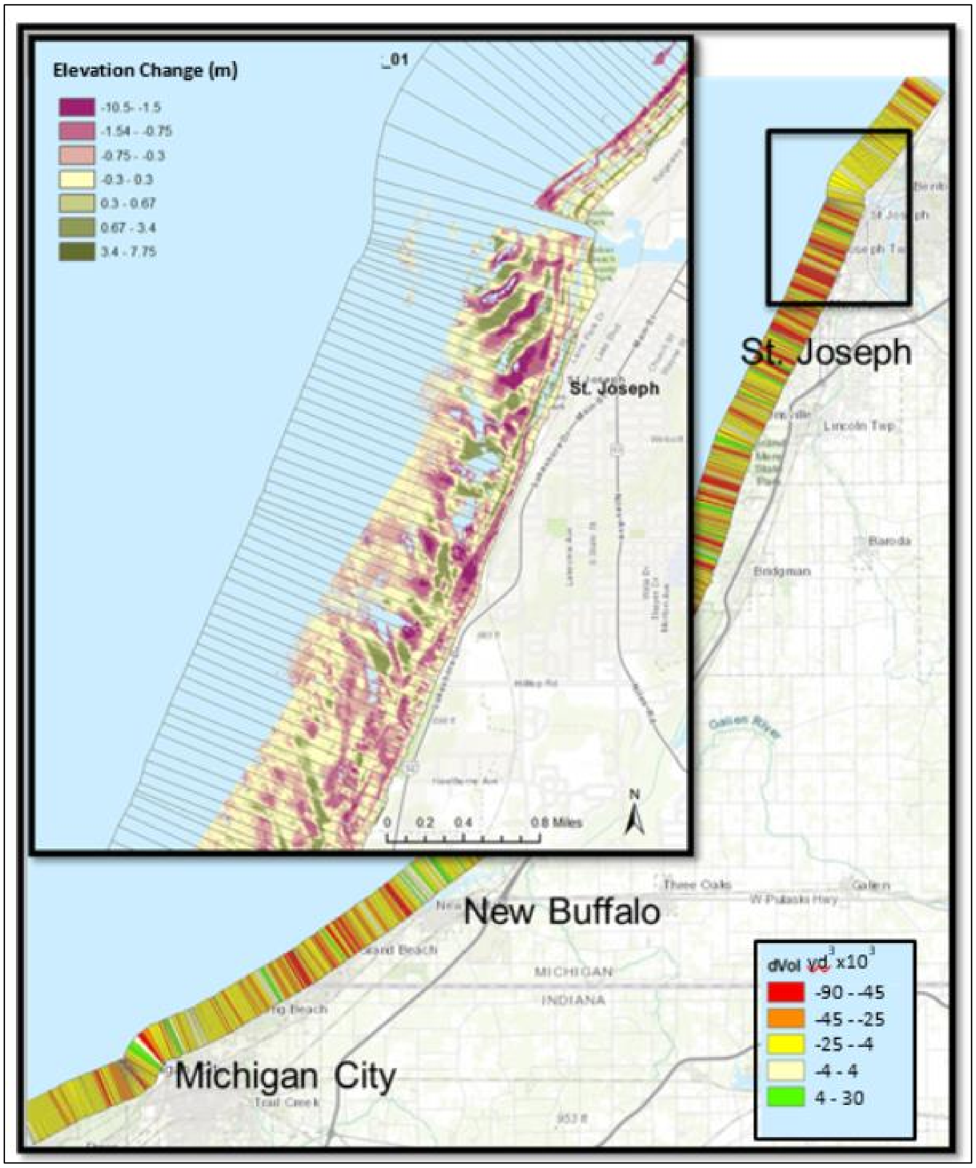

Figure 3. JALBTCX Volume Change Toolbox analysis bins, colored by total volume change, are shown across an area of southeast Lake Michigan. Inset: the original difference grid for a sub-section is shown with analysis bins.

The JALBTCX Volume Change Toolbox provides a standard process to generate the bins and quantify volume and shoreline change values for a region. Using the lidar datasets and workflow to create the bins into SBAS helps standardize and increase the efficiency of sediment budget cell creation and reduces manual requirements to draw these cells and populate the values.

SEDIMENT BUDGET ANALYSIS SYSTEM (SBAS): SBAS is an ArcGIS toolbox that supports the districts with sediment budget creation and visualization. It utilizes the fundamental sediment budget equation in combination with user-drawn ArcGIS features to illustrate sediment budget cells and fluxes (Equation 1).

$$\sum Q_{source} - \sum Q_{sink} - \Delta V + P - R = Residual \quad (1)$$

Inputs to a given sediment budget cell are represented by arrows either in (contributing to $\sum Q_{source}$) or out (contributing to $\sum Q_{sink}$). The total volume change within the cell (ΔV) plus the placement volume (P) minus volume removed (R) should be equal to the sum of sources minus the sum of sinks. If this is not the case, a residual ($Residual$) remains.

Recent updates to the SBAS include improvements to allow users to convert features from outside of SBAS directly into sediment budget cells with sediment budget attributes. This will allow outside datasets, such as transects and bins and volume results created using the JALBTCX Volume Change Toolbox, to be used seamlessly in the SBAS and create the littoral cells and populate the user-defined field (Figure 3). The total volume change within analysis bins from the JALBTCX Volume Change Toolbox can feed directly into an SBAS analysis.

To prepare the data, the user will combine the desired number of analysis bins into one sediment budget cell. One of the standard fields created in the JALBTCX Volume Change Toolbox workflow is the “Segment,” which is a unique identifier for grouping areas (Figure 4). In addition, within each Segment, the unique bins are labeled with transect numbers (stTranNum) as seen in Figure 4. The start and end date align with the date range for the surveys used in the analysis for the volume change. dDensity is the net volume change per linear foot, and dVol is the net volume change within the individual bin. dMHW_Vol2 is the subaerial volume change. Contour change is also quantified using the JALBTCX Volume Change Toolbox. The dDensity MHW2 and dMHW_Rate_Ft corresponds to the shoreline or other contour file per linear foot alongshore and the average rate of contour change, respectively (Robertson et al. 2018).

State	Segment	stTranNum	Start_Date	End_Date	dDensity	dVol	dMHW_Vol2	dDensity MHW2	dMHW_ Rate_ft	dVol_CU ydyr
MI	1	10	20080901	20120901	-111	-36350	-2378	-7.2	-9.6	-9088
MI	1	11	20080901	20120901	-45	-14647	-1	0	-6.0	-3662
MI	1	12	20080901	20120901	-44	-14294	1791	5.5	-1.8	-3574
MI	1	13	20080901	20120901	-83	-27363	2359	7.2	-2.5	-6841
MI	1	14	20080901	20120901	-103	-33868	775	2.4	0.8	-8467
MI	2	15	20080901	20120901	-59	-19294	1116	3.4	4.5	-4824
MI	2	16	20080901	20120901	-15	-4967	441	1.4	10.2	-1242
MI	2	17	20080901	20120901	-24	-7953	766	2.3	11.6	-1988
MI	2	18	20080901	20120901	0	-28	902	2.7	8.1	-7
MI	2	19	20080901	20120901	-16	-5335	-170	-0.5	12.9	-1334
MI	2	20	20080901	20120901	-56	-18421	-2798	-8.6	-1.6	-4605

Figure 4. Example attribute table from the JALBTCX Volume Change Toolbox final output files.

Each bin has an associated net volume change (dVol) and volume change per year (dVol_CUydyr), which is combined per Segment or littoral cell to provide an accurate value for ΔV in the sediment budget equation. The automated process to link the cell volume change (ΔV) with the littoral cell significantly reduces manual data manipulation.

Additionally, the update in SBAS also allows for other outside SBAS features to be incorporated into the system. Polygons generated from other sources that include volume or flux attributes can be imported directly into SBAS. In previous versions, users hand-digitized sediment budget cells and fluxes and manually entered all values. This is a crucial improvement allowing for cells and volumes to be represented accurately. The bins generated using the JALBTCX Volume Change Toolbox may be combined to represent littoral cells for use in SBAS. In Figure 5, the bins in yellow (Figure 5, left) are merged to form littoral cells that are used in the SBAS. The merged cells are used to account for sources, sinks, volume change, placement of material, or removal for the sediment budget analysis (Figure 5, right). The fluxes between cells are added directly within SBAS.

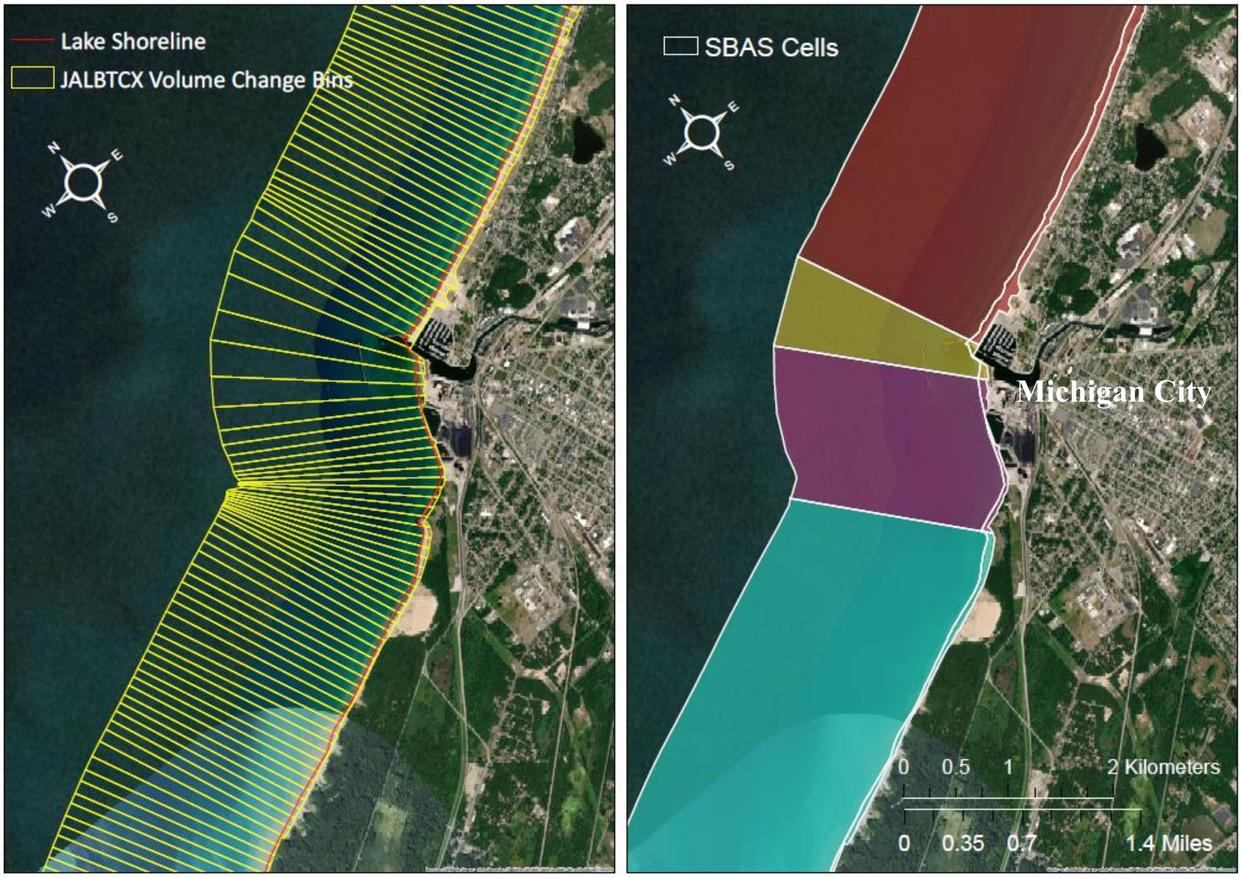

Figure 5. JALBTCX volume change bins (left) used as the SBAS cells for sediment budget analysis (right).

Another update to the SBAS is the direct link with web services. The JALBTCX volume change web services are accessible through the JALBTCX website (*https://jalbtcx-live.azurewebsites.net/*) or directly through web services (Figure 6 and Figure 7). Steps to connect to an ArcGIS server are outlined in Figure 7 and are shown for ArcGIS Desktop 10.5. Link for the connection to the JALBTCX data is *http://usace-ags.esriemcs.com/arcgis/services/*. The user name and password should be left blank.
https://arcgis.usacegis.com/arcgis/rest/services/JALBTCX/JALBTCX_Products_1mGrid/ImageServer/query?outFields=&where=1%3D1*

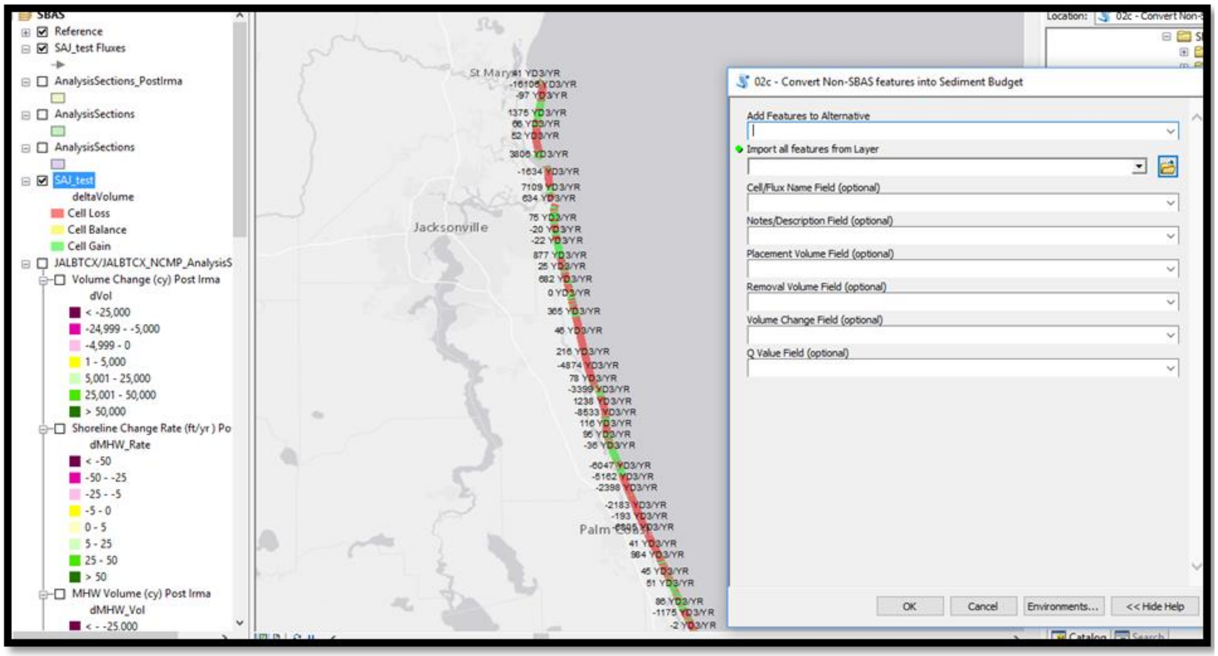

Figure 6. The SBAS toolbox update offers an ArcGIS tool to convert non-SBAS features into Sediment Budgets.

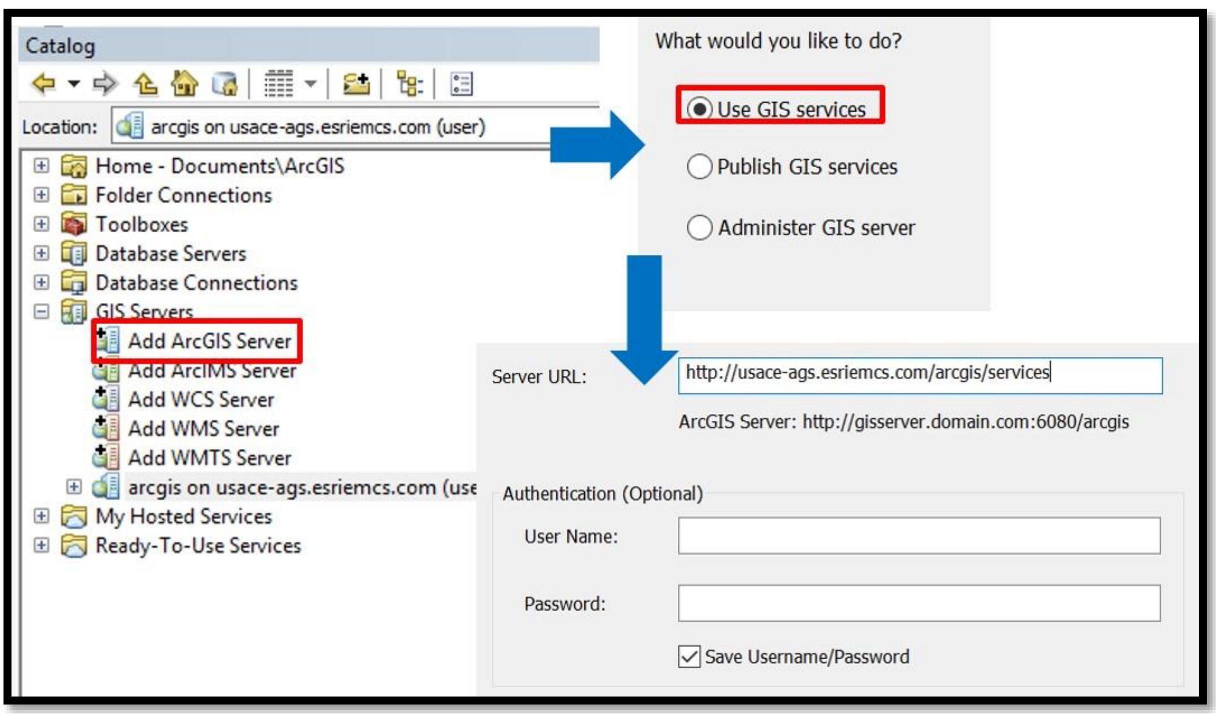

Figure 7. Steps to connect to an ArcGIS server are outlined and are shown for ArcGIS Desktop 10.6. Link for the connection to the JALBTCX data is *http://usace-ags.esriemcs.com/arcgis/services/*. The user name and password should be left blank.

CASE STUDY: Following the methods developed for the Lake Erie historical sediment budget (Cross et al. 2016), the Great Lakes Region is in the process of updating and developing sediment budgets to support the Great Lakes Restoration Initiative. In order to develop conceptual sediment budgets for the entire region along the Great Lakes, the updates to the

SBAS are important since this is a large geographic region and automated steps are critical to the success of the project. The JALBTCX collected lidar surveys in 2008 and in 2012. These lidar datasets are uniquely available to provide high-resolution elevation data and to compare the datasets for volume change.

The SBAS toolbox was used to convert the volume change bins into sediment budget littoral cells. The cells were created by combining analysis bins to create larger SBAS cells based on geomorphology and location of channels and coastal structures. This allowed the values from the volume change calculation to be preserved in the indidivual SBAS cells. The automated step eliminates the need for manual data input and preserves the detailed delineation of the bathymetric volume change and the topographic volume change. Elevation change is shown in Figure 3 (inset).

The bathymetric volume change between 2008 and 2012 is predominantly erosional for this region of Lake Michigan, as indicated by the red littoral cells in Figure 8. The landward portion of the analysis section indicates accretion along the shoreline near St. Joe Harbor.

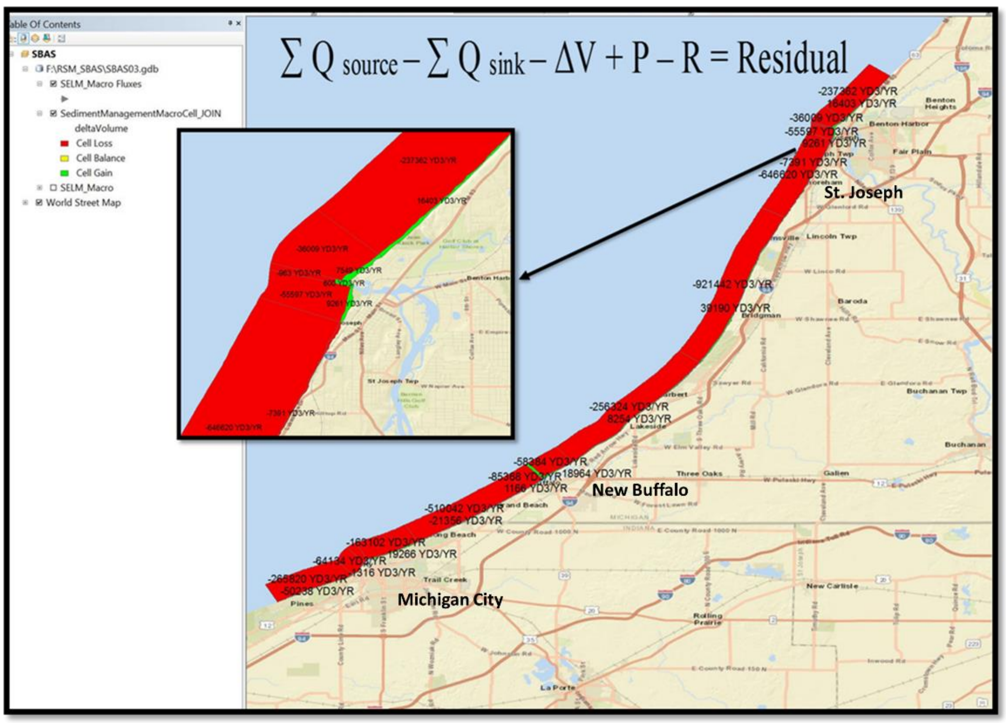

Figure 8. Sediment Budget example for Lake Michigan near St. Joe Harbor.

SUMMARY: This RSM-TN has summarized the workflow developed to create littoral cells from JALBTCX Volume Change Toolbox bins and integrate lidar-derived volume change outputs from the JALBTCX toolbox into the SBAS. This newly developed process greatly increases the efficiency and accuracy of the sediment budget development process by automating many of the most time-consuming steps. Users can now easily create SBAS cells with associated lidar-derived volume changes for a large region with these automated processes. The case study shown here outlines the use of these methods in a current effort to develop a sediment budget for the US Great Lakes shorelines, specifically highlighting work along Lake Michigan.

ADDITIONAL INFORMATION: This RSM-TN was prepared as part of the US Army Corps of Engineers (USACE), Regional Sediment Management (RSM) Program, by Lauren Dunkin, Eve Eisemann, Michael Hartman, and Jennifer Wozencraft, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Vicksburg, MS. Questions pertaining to this RSM-TN may be directed to Lauren Dunkin (*Lauren.M.Dunkin@usace.army.mil*), Eve Eisemann (*Eve.R.Eisemann@usace.army.mil*), or to the USACE RSM Program Manager, Dr. Katherine E. Brutsché (*Katherine.E.Brutsche@usace.army.mil*). Additional information regarding RSM may be obtained from the RSM web site *http://rsm.usace.army.mil/*.

This ERDC/TN RSM-20-4 should be cited as follows:

> Dunkin, L. M., E. R. Eisemann, M. A. Hartman, and J. M. Wozencraft. *Seamless Integration of Lidar-Derived Volumes and Geomorphic Features into the Sediment Budget Analysis System.* ERDC/TN RSM-20-4. Vicksburg, MS: US Army Engineer Research and Development Center. *http://dx.doi.org/10.21079/11681/36296*

REFERENCES

Baird, W. F., & Associates Coastal Engineers Ltd. 2002. *Regional Sediment Management (RSM), Sediment Budget for St. Joseph, MI to Michigan City, IN*. Prepared for Detroit District USACE. W. F. Baird & Associates, Coastal Engineers Ltd.

Camfield, F. E., and A. Morang. "Defining and Interpreting Shoreline Change." *Ocean and Coastal Management* 32(3): 129–151.

Cross, W. P., A. Morang, A. E. Frey, M. C. Mohr, S. A. Chader, and C. M. Forgette. 2016. *Historical Sediment Budget (1860s to Present) for the United States Shoreline of Lake Erie.* ERDC/CHL TR-16-15. Vicksburg, MS: US Army Engineer Research and Development Center.

Dolan, T. J., P. G. Castens, C. J. Sonu, and A. K. Egens . 1987. "Review of Sediment Budget Methodology: Oceanside Littoral Cell, California." *Proceedings, Coastal Sediments '87.* Reston, VA: ASCE.

Kana, T., and F. Stevens. 1992. "Coastal Geomorphology and Sand Budgets Applied to Beach Nourishment." *Proceedings Coastal Engineering Practice '92.* Reston, VA: ASCE.

Robertson Q., L. Dunkin, Z. Dong, J. Wozencraft, and K. Zhang. 2018. "Florida and US East Coast Beach Change Metrics Derived from LiDAR Data Utilizing ArcGIS Python Based Tools." Edited by C. Botero, O. Cervantes, C. Finkl. *Beach Management Tools - Concepts, Methodologies and Case Studies*. Coastal Research Library, vol 24. Springer.

Rosati, J. D. 2005. "Concepts in Sediment Budgets." *Journal of Coastal Research* 21(2): 307–322.